# Using high-resolution airborne remote sensing to study aerosols near clouds



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# The “twilight” around clouds

What appears as clear sky around a cloud as seen from the ground through a digital camera (left) actually has a twilight zone of light-reflecting particles around it (right).

(The blue light from the atmosphere in the original image is first subtracted (middle). The twilight zone is revealed after the darker parts of the image are enhanced (right). )

So what is this twilight stuff?

NASA’s Earth Observatory, and Koren et al., 2008

# Application of eMAS data to quantifying the aerosol indirect effect

Eric Wilcox and Lan Gao, Desert Research Institute

Aerosol indirect effect and forcing has been evaluated in global models using the ACI (e.g. Quaas et al. 2009):

ACI = —dln($r_e$)/dln(AOD), the change in cloud drop size (or cloud optical thickness) with increasing AOD

But in-situ measurements suggest a stronger aerosol effect than satellite data (McComisky and Feingold, 2012)

**ACI depends on the resolution of your measurement.**

*A challenge for constraining the indirect effect: small cumulus clouds embedded in haze*

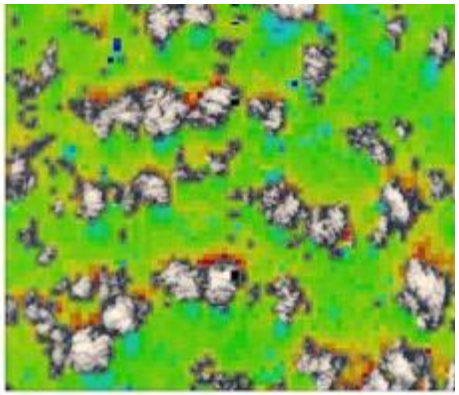
How do we bridge the gap in scales between satellite and in-situ data?

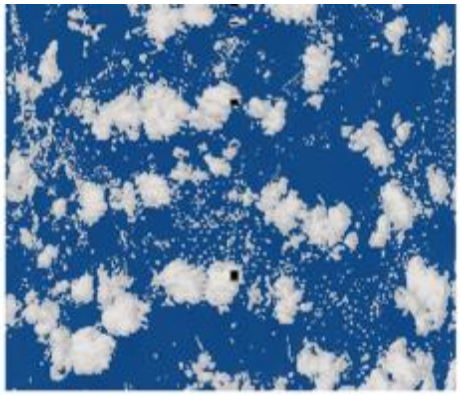
**Key research questions to be addressed:**

**How does the derivation of ACI vary across measurements from different resolution?**

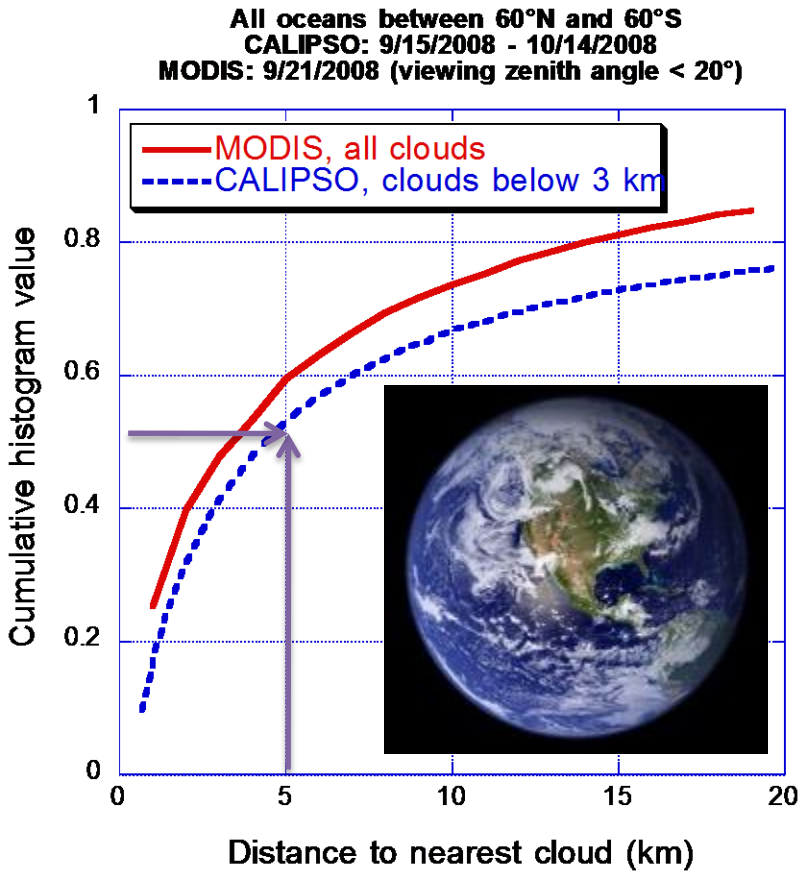
**How much of the variation is due to smoothing of aerosol and cloud fields?**

**And how much is due to 3-D effects?**



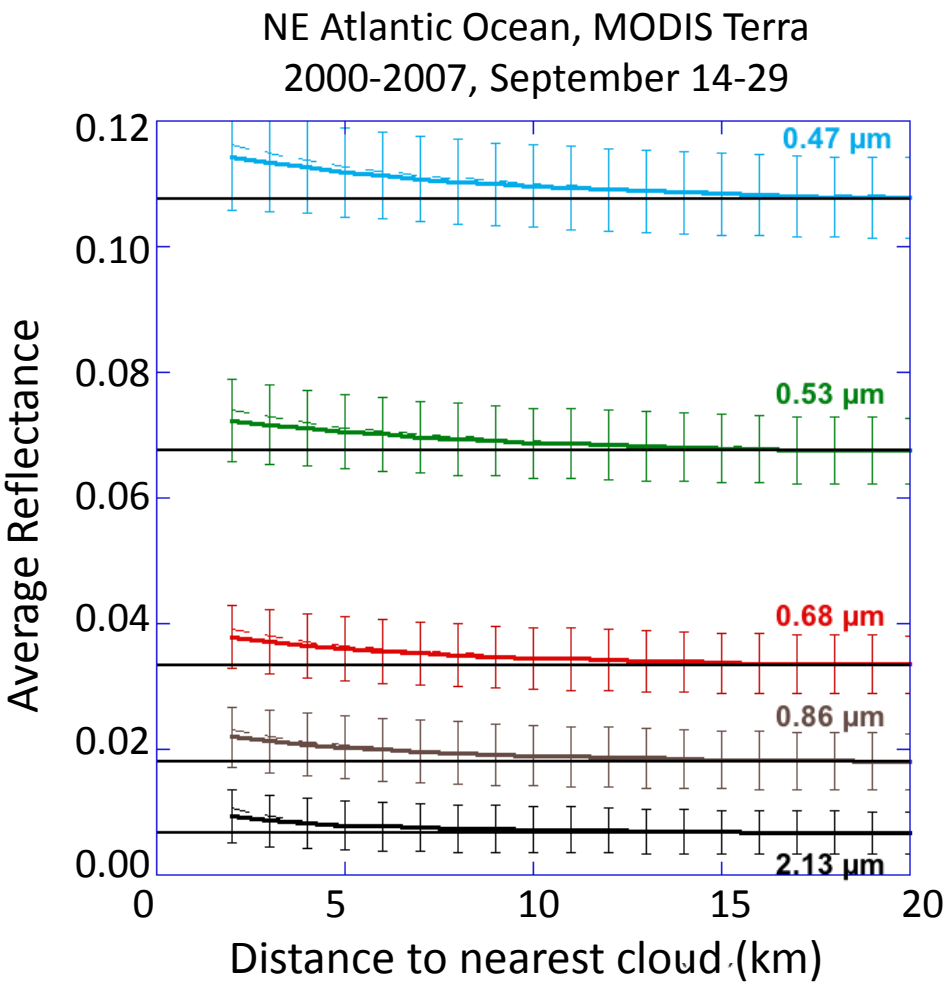



# Motivation




from **MODIS or CALIPSO**: 50-60% of all clear sky pixels are located 5 km or less from all clouds

Várnai and Marshak (2009)




- Reflectance increases near cloud
- Retrieved AOT increases closer to cloud

Marshak, Várnai, Wen, Wang et al.,

# Clearly, retrieved AOT is greater near clouds

However, it is not clear yet how much the enhancement comes from:

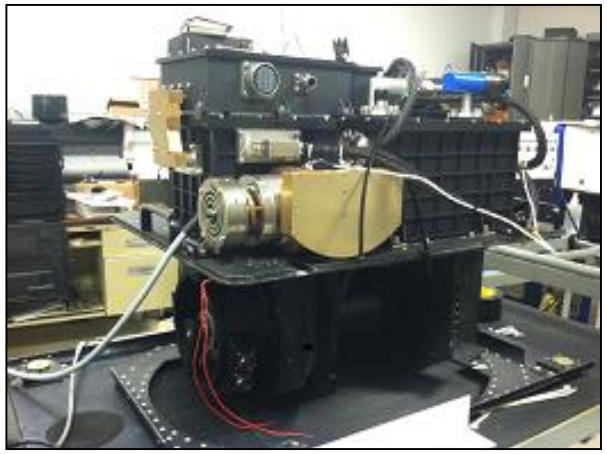
- "real" microphysics, e.g.
  - increased hydroscopic aerosol particles,
  - new particle production or
  - other in-cloud processes.

- "artificial" effects, e.g.
  - cloud contamination (sub-pixel clouds),
  - extra illumination from clouds (a clear pixel in the vicinity of clouds)
  - sampling issue

- The "artificial" effects may lead to significantly overestimated AOT.
- The "real" effects may never be sampled from MODIS, especially within 1-2 km.

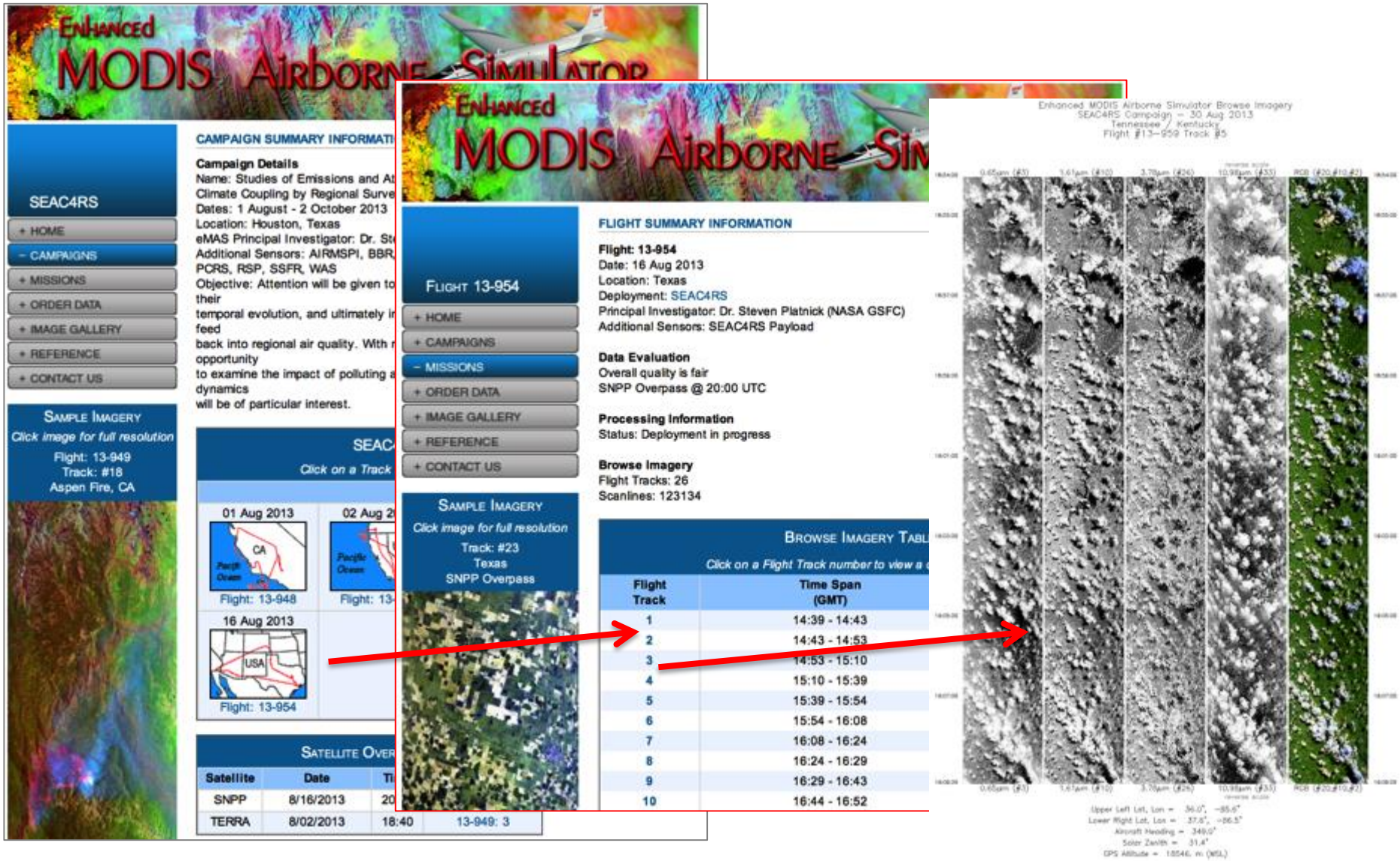
- **Enter: eMAS and SEAC4RS!**


- NASA imager maintained by NASA Ames Airborne Sensor Facility.
- MAS vs MODIS
  - MAS has 38 spectral channels (VNIR-LWIR) vs MODIS that has 36 channels
  - MAS has 50 m nadir spatial resolution and 37 km swath from 20 km altitude (ER-2) vs MODIS with 500 m pixel and 2330 km swath from ~700 km (Terra & Aqua)
- The "e": Upgraded with a new infrared spectrometer.
- **Long history as MAS, back into the 1990s!**
- **MAS "is" the MODIS simulator!**
- Further information: http://mas.arc.nasa.gov



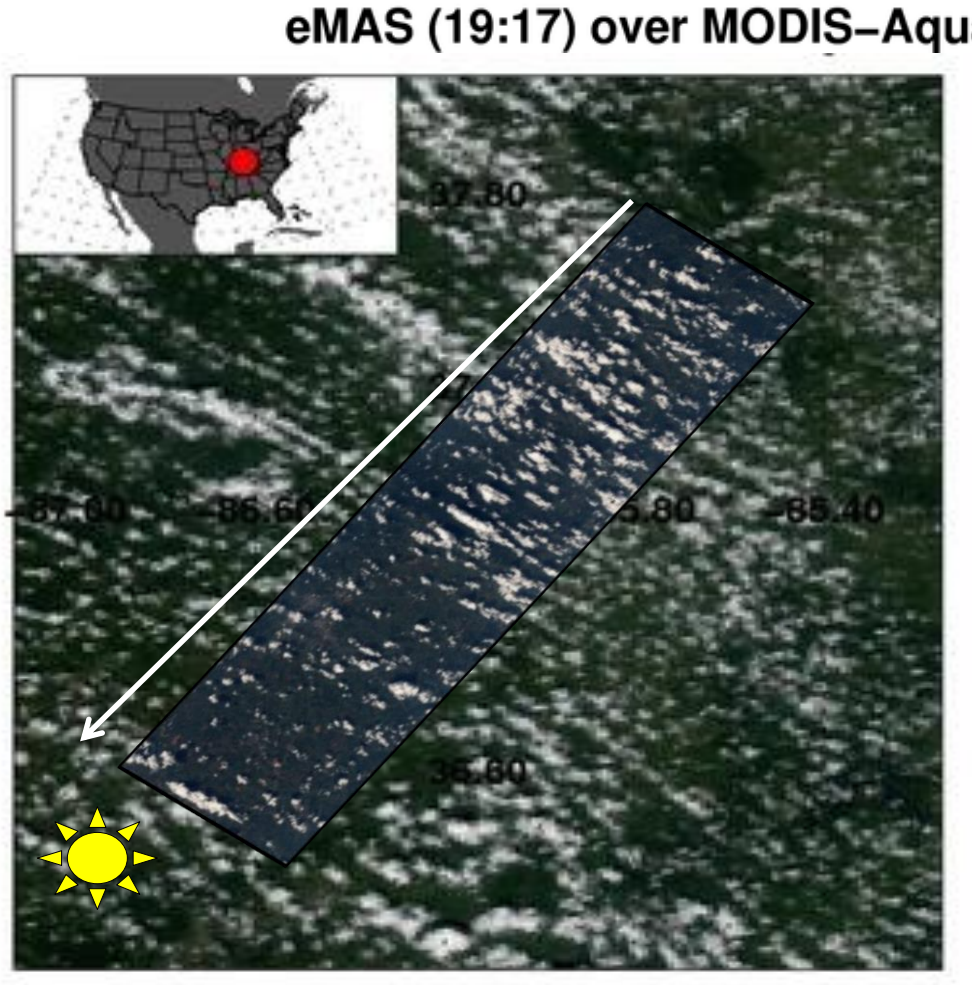
| *Band* | λ (μm) | Δλ (μm) |
|---|---|---|
| 1 | 0.47 | 0.040 |
| 2 | 0.55 | 0.044 |
| 3 | 0.66 | 0.053 |
| 4 | 0.70 | 0.042 |
| 5 | 0.75 | 0.041 |
| 6 | 0.83 | 0.042 |
| 7 | 0.87 | 0.042 |
| 8 | 0.91 | 0.033 |
| 9 | 0.95 | 0.046 |
| 10 | 1.61 | 0.052 |
| 11 | 1.66 | 0.052 |
| 12 | 1.72 | 0.050 |
| 13 | 1.78 | 0.049 |
| 14 | 1.83 | 0.046 |
| 15 | 1.88 | 0.045 |
| 16 | 1.93 | 0.045 |
| 17 | 1.98 | 0.048 |
| 18 | 2.03 | 0.048 |
| 19 | 2.08 | 0.047 |
| 20 | 2.13 | 0.047 |
| 21 | 2.18 | 0.047 |
| 22 | 2.23 | 0.047 |
| 23 | 2.28 | 0.046 |
| 24 | 2.33 | 0.047 |
| 25 | 2.38 | 0.047 |
| M1 | 3.74 | 0.183 |
| L1 | 6.72 | 0.253 |
| L2 | 7.33 | 0.260 |
| L3 | 8.28 | 0.264 |
| L4 | 8.55 | 0.264 |
| L5 | 9.73 | 0.262 |
| L6 | 10.20 | 0.261 |
| L7 | 11.03 | 0.260 |
| L8 | 12.02 | 0.258 |
| L9 | 12.60 | 0.255 |
| L10 | 13.34 | 0.263 |
| L11 | 13.64 | 0.259 |
| L12 | 13.94 | 0.253 |

# eMAS L1B Browse Imagery (http://mas.arc.nasa.gov)




Many previous campaigns (since 1990's) including TARFOX, CLAMS, TC4, Milagro, etc

# High resolution cloud features in eMAS (under flying MODIS)

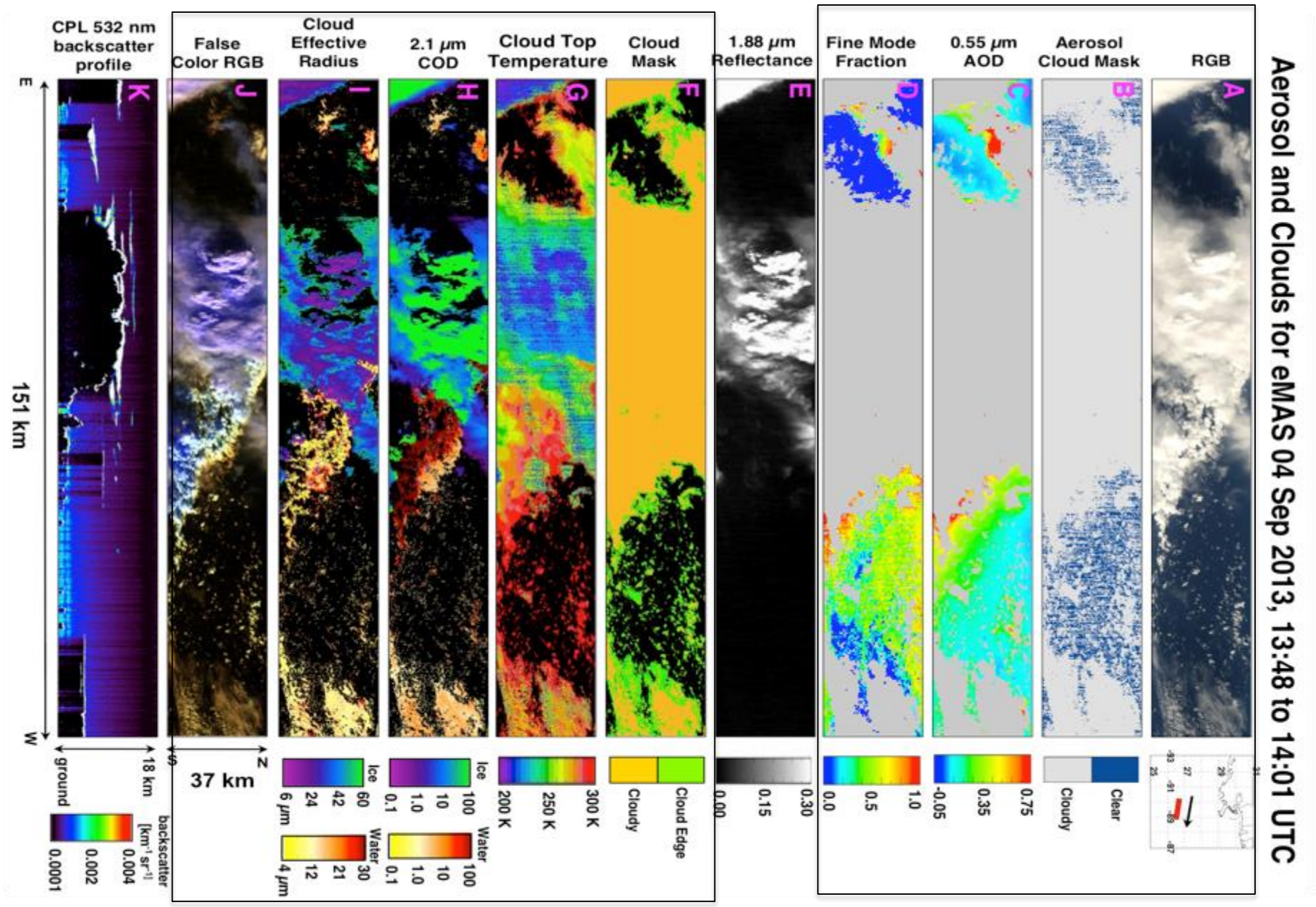



PI cloud product suite (masking, cloud-top, optical properties) produced with MODIS-like Collection 6 algorithms. (Platnick et al.)

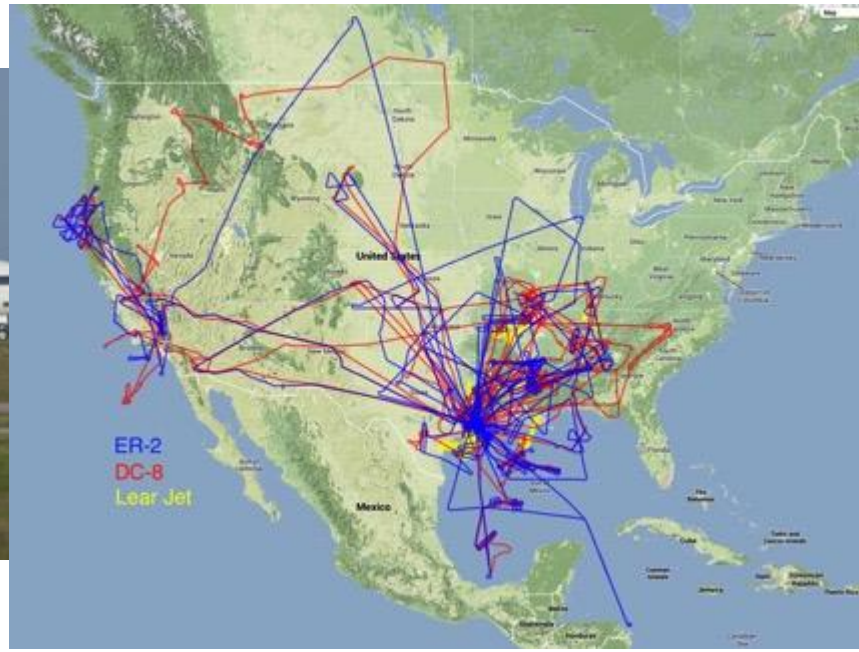
Can we do the same thing with aerosol retrieval?

Of course we can! MAS was used to create MODIS aerosol retrieval in the first place!

# Our product goal: Example: Sep 4, 2013
# Cloud AND Aerosol retrievals! (all at high resolution!)



# Studies of Emissions & Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC$^4$RS): August-September 2013

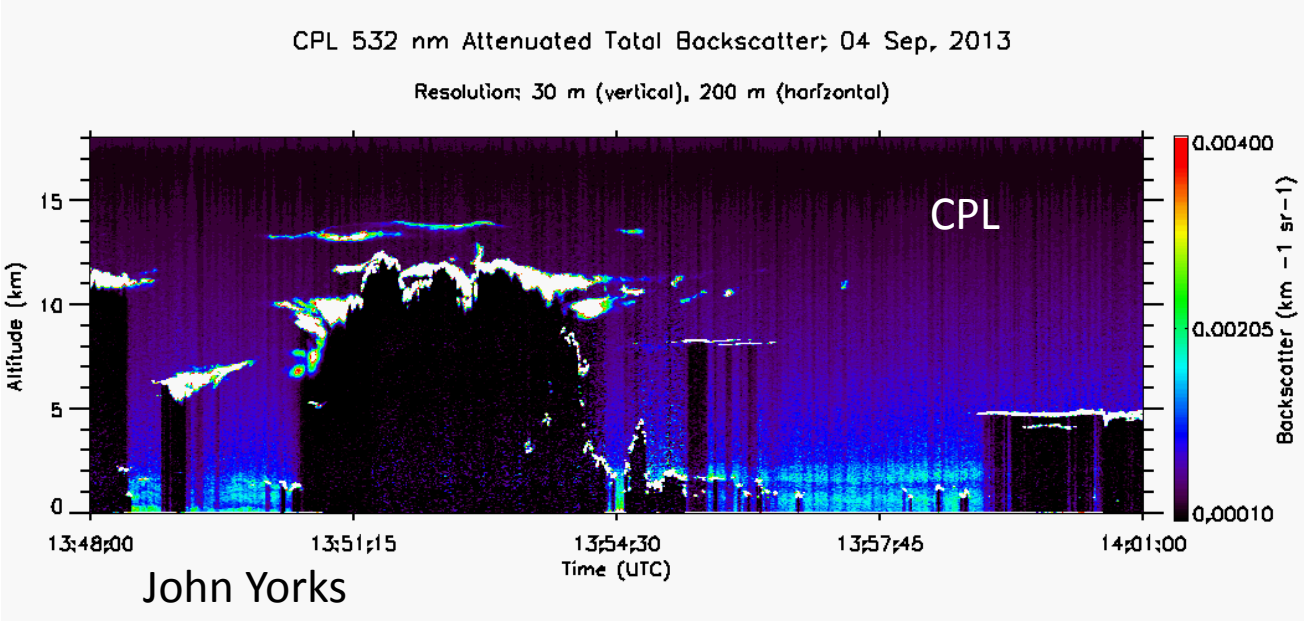



- 3 Aircraft (including high flying ER-2 with eMAS )
- Lots of ground measurements
- NASA/NOAA/etc
- Lots of lots of science objectives
- Co-incident with DISCOVER-AQ (Houston)
- http://espo.nasa.gov/missions/seac4rs/

# Apply MODIS Dark target (DT) retrieval

- eMAS algorithm ≈ MODIS algorithm
  - For now, we assume decision-making tests are the same (cloud-masking, pixel selection) and have to meet similar thresholds.
  - Instead of grouping 500 m / 1 km pixels for 10 km retrieval, we group 50 m pixels for 500 m retrieval
- Data processed locally at GSFC, using calibration fine-tuned by Tom Arnold et al.
- Products: AOD (at 0.55 μm) over land and ocean, Angstrom Exponent and/or Fine Mode Fraction over ocean.
- Note: There is no 0.41 μm channel on MAS (cannot do Deep Blue), and no consistent surface target sampling (cannot do MAIAC). So DT it is.

# Examples of collaborative and validation data




John Yorks

Cloud Physics Lidar (CPL)
also flying on ER-2

Can help evaluate cloud mask, aerosol and cloud layers


Holben et al.,

AERONET / 4STAR sunphotometers

Including high-density DRAGON over Houston

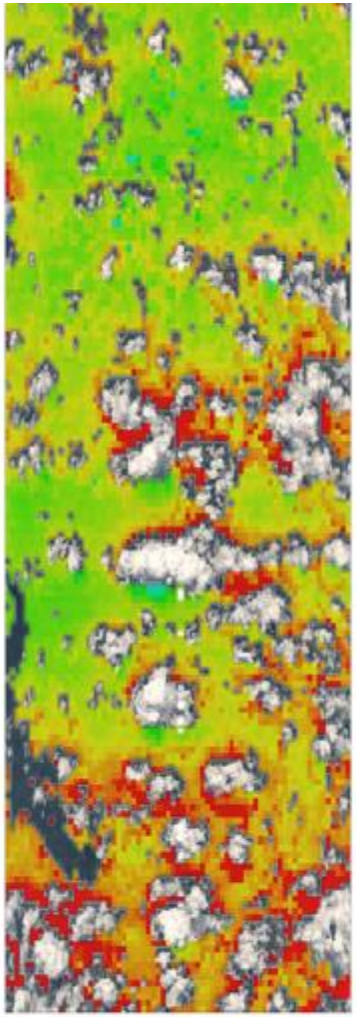
# Retrieval near Mammoth Cave (Aug 30 @ 19:24)

RGB

Segment is 19:21-19:26

Aerosol Cloud Mask

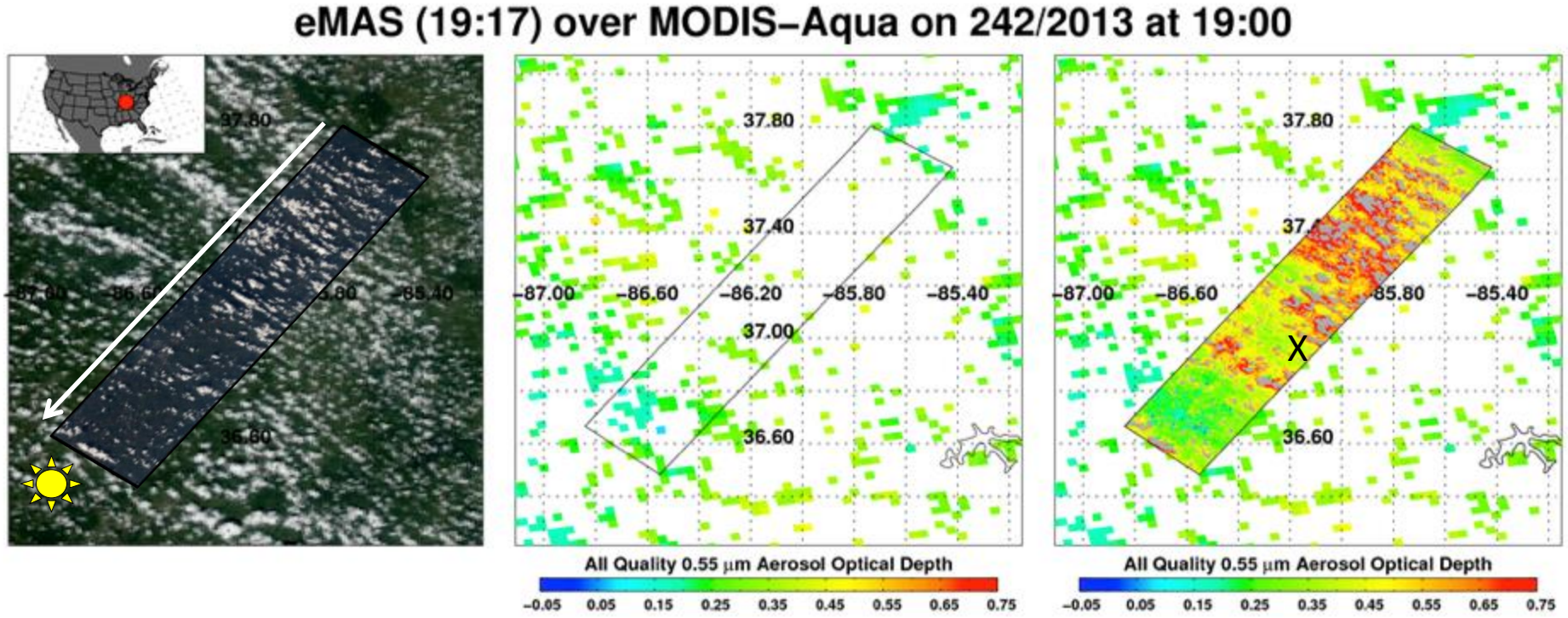

AOD




Wisc. Cloud Mask


1.88 μm Reflect

# Over flight of MODIS-Aqua (Aug 30 @ 19:00)
# AERONET observed 0.28




MODIS chose to filter out the clouds. eMAS gets in between.
This needs to be validated with SEAC4RS data

# MODIS DT algorithm on eMAS

- eMAS algorithm ≈ MODIS algorithm
- Aerosol retrieval at for 500 m resolution
- We have a “beta” version of products, and are sharing with project Co-Is and will soon be available on SEAC4RS web sites
- We will learn about aerosols near clouds in MODIS data, but first we have to validate the eMAS retrievals

# Some examples from SEAC$^4$RS

- The following examples represent some interesting cases/issues
- For images, pieces of flight segments have been split into approx 5 minute sections, or approximately 120 x 37 km sections.
- CPL cloud detection drawn along nadir (either in white or black)
- Aerosol cloud mask uses 3x3 spatial variability.
- Very little validation yet. But it is time to get started!

# August 30, 2013 w/AOTs

## Cumulus and Pollution

Missouri

Kentucky

Tennessee

Arkansas

Mississippi

Alabama

Louisiana

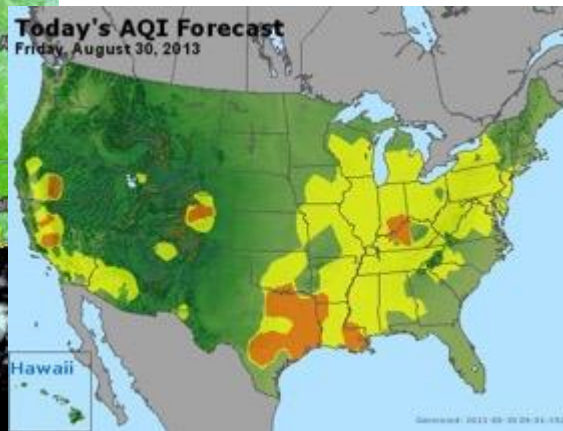
Mammoth Cave (0.24)
Mingo (0.13)

Huntsville (0.47)

Yorkville (0. 5)

Leland (0.5)
Birmingham (4star-)

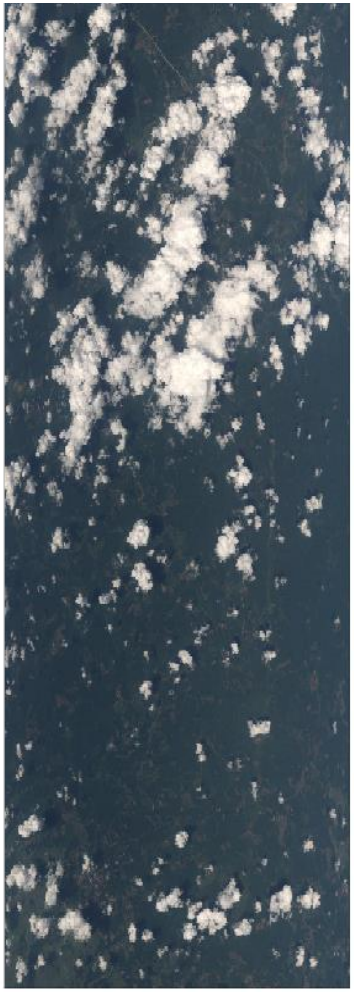
Centreville x2
(0.4-0.5)




From Jeff Reid

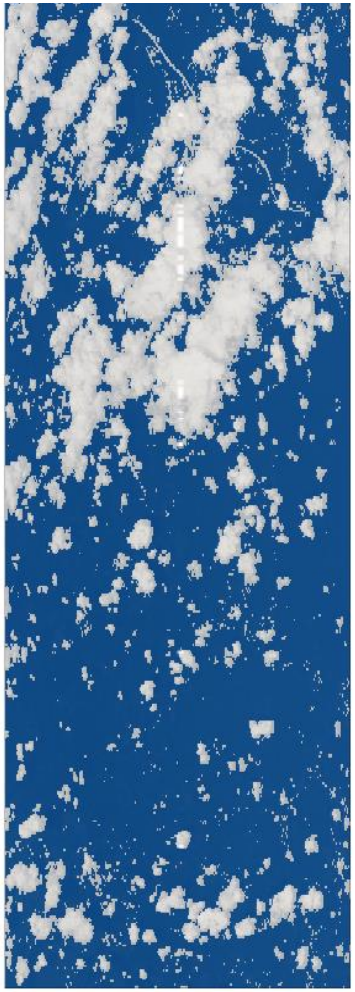
# Retrieval near Centerville (Aug 30 @ 18:08)
# AERONET observed 0.4-0.5

RGB

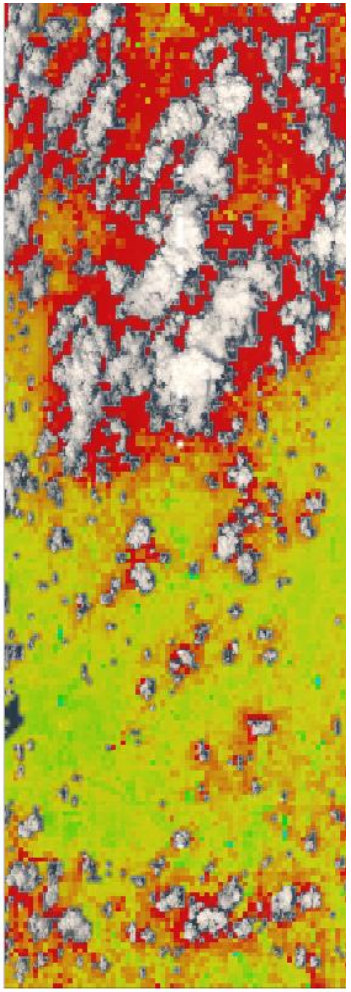


Segment is
18:05-18:10

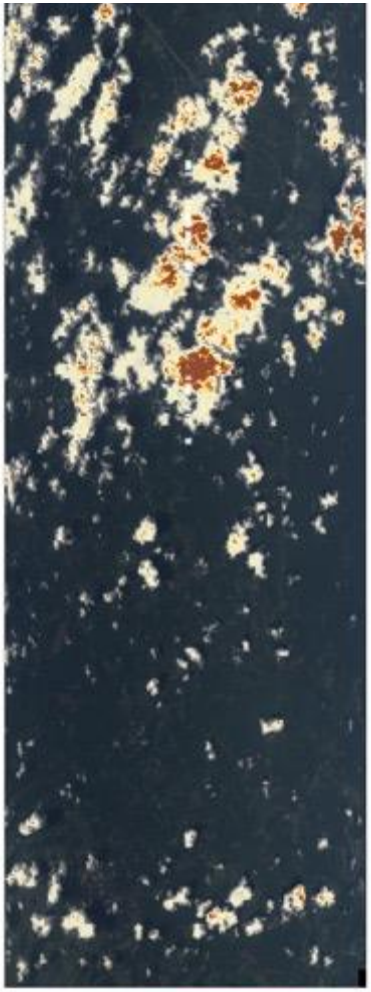
Aerosol Cloud Mask




AOD




COD




1.88 μm Reflect

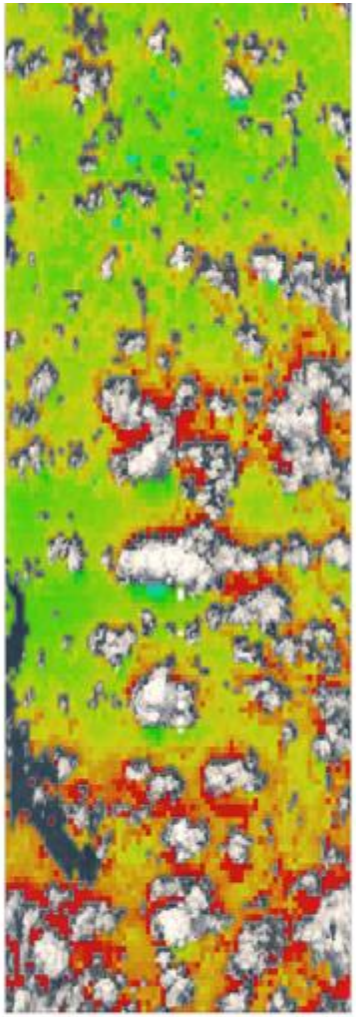
# Retrieval near Mammoth Cave (Aug 30 @ 19:24)
# AERONET observed 0.25

RGB

Segment is
19:21-19:26

Aerosol Cloud Mask


AOD



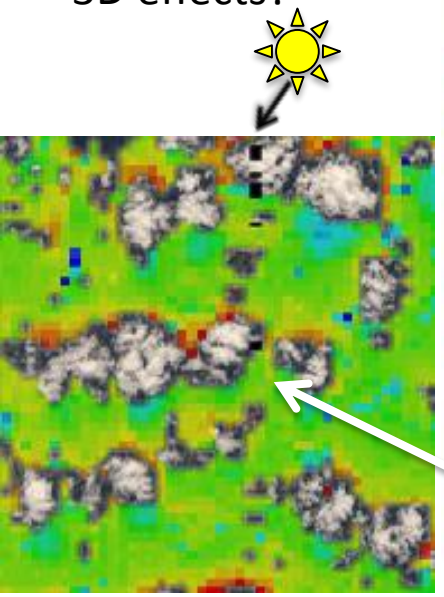

Wisc. Cloud Mask


1.88 μm Reflect

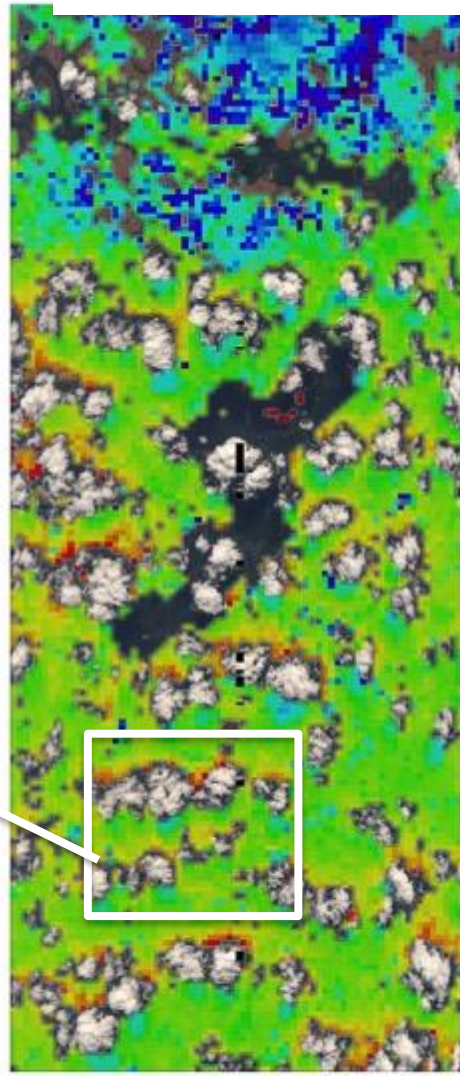
# More cases

# Popcorn clouds from Sep 9

Note sun direction and 3D effects?



AOD



0.0 0.5 1.0

CPL identified cloud

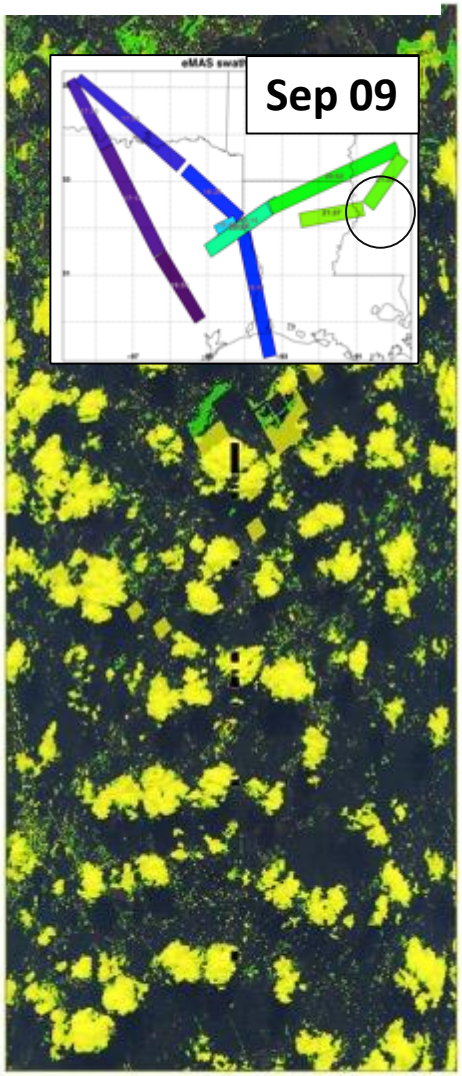
Aerosol/Cloud

Aerosol Cloud Mask

Cloudy Clear

CPL identified cloud

Wisc Cloud Mask




MOD35–like Cloud Mask

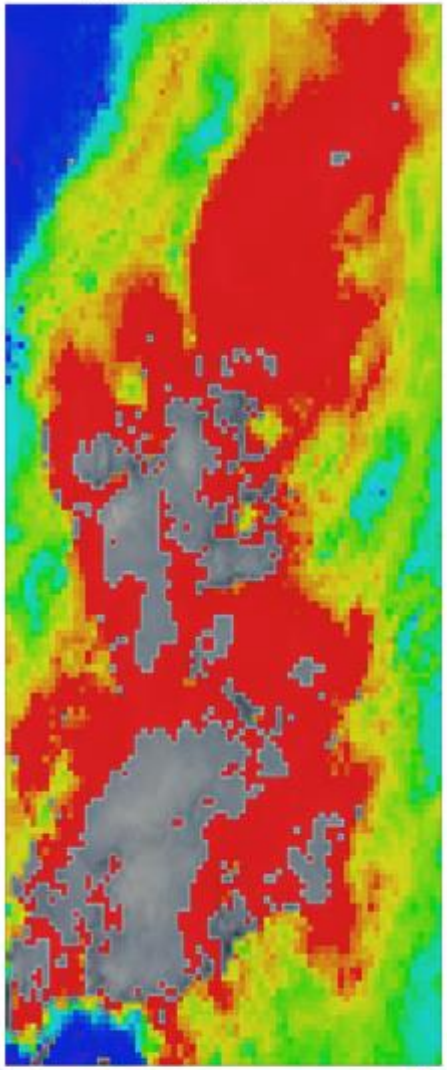
Conf. Cloud Prob. Cloud Prob. Clear

CPL identified cloud

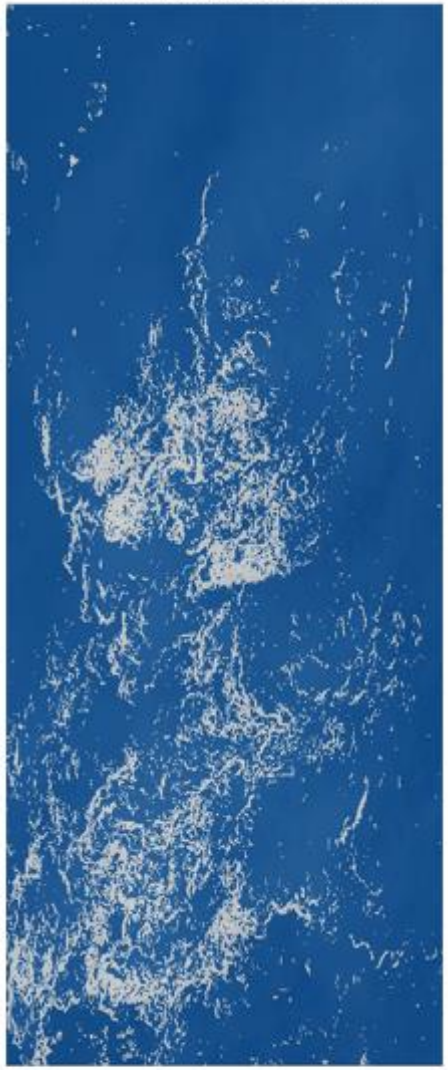
# Aug 2, Fire over CA/OR (around 21 UTC)

RGB

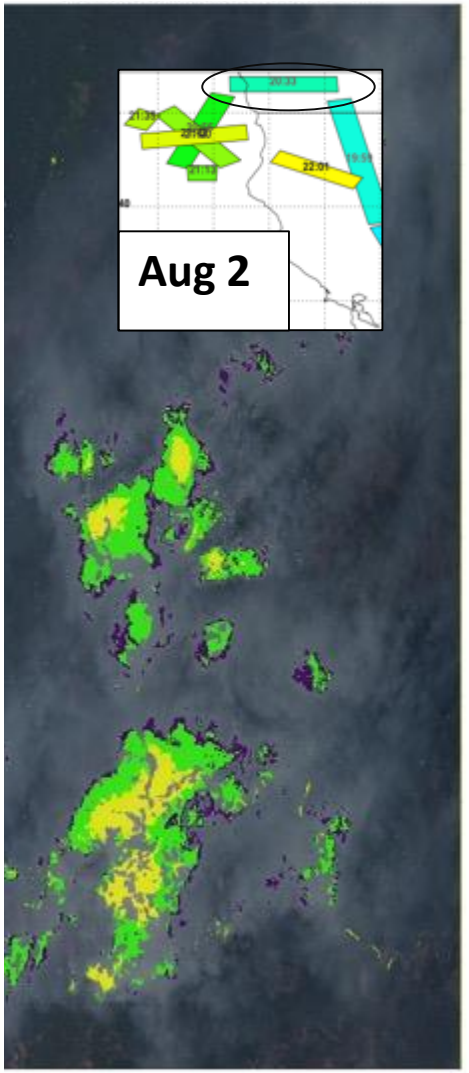
AOD




Aerosol Cloud Mask

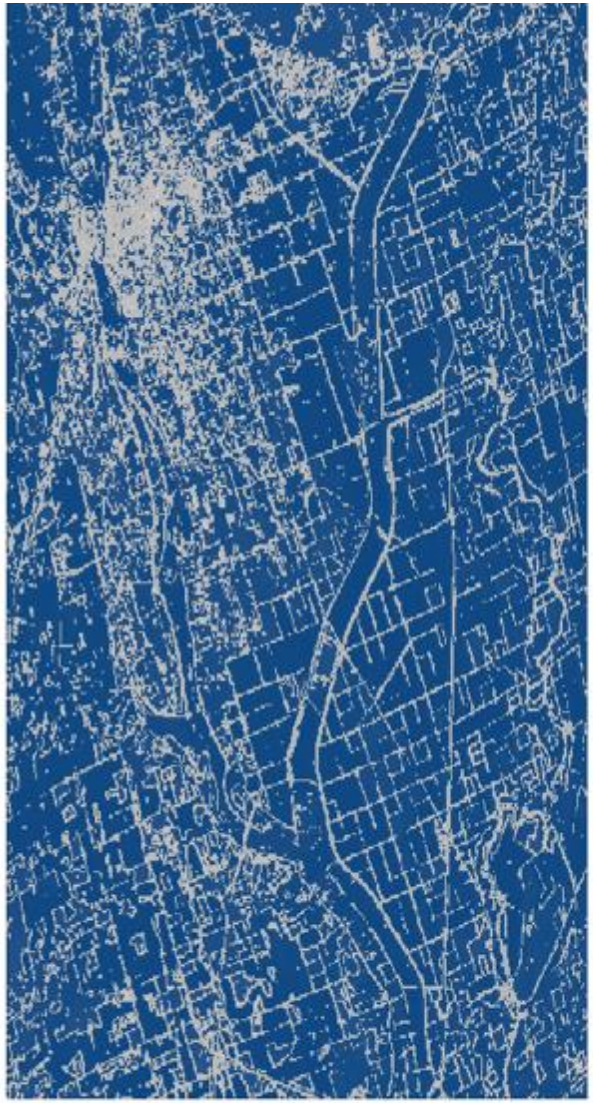



Wisc. Cloud Mask



# August 2 Sacramento and ‘burbs and farms: Note 3x3 aerosol cloud mask finds roads

Aerosol Cloud Mask

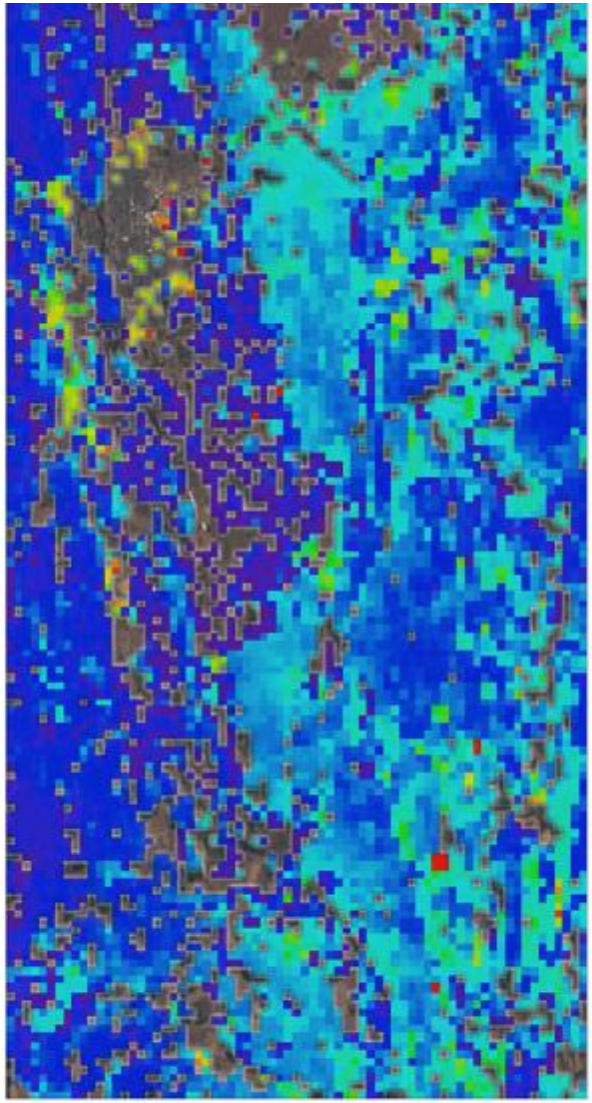


Aerosol Cloud Mask

Cloudy Clear

CPL identified cloud

AOD



0.0 0.35 0.75

CPL identified cloud

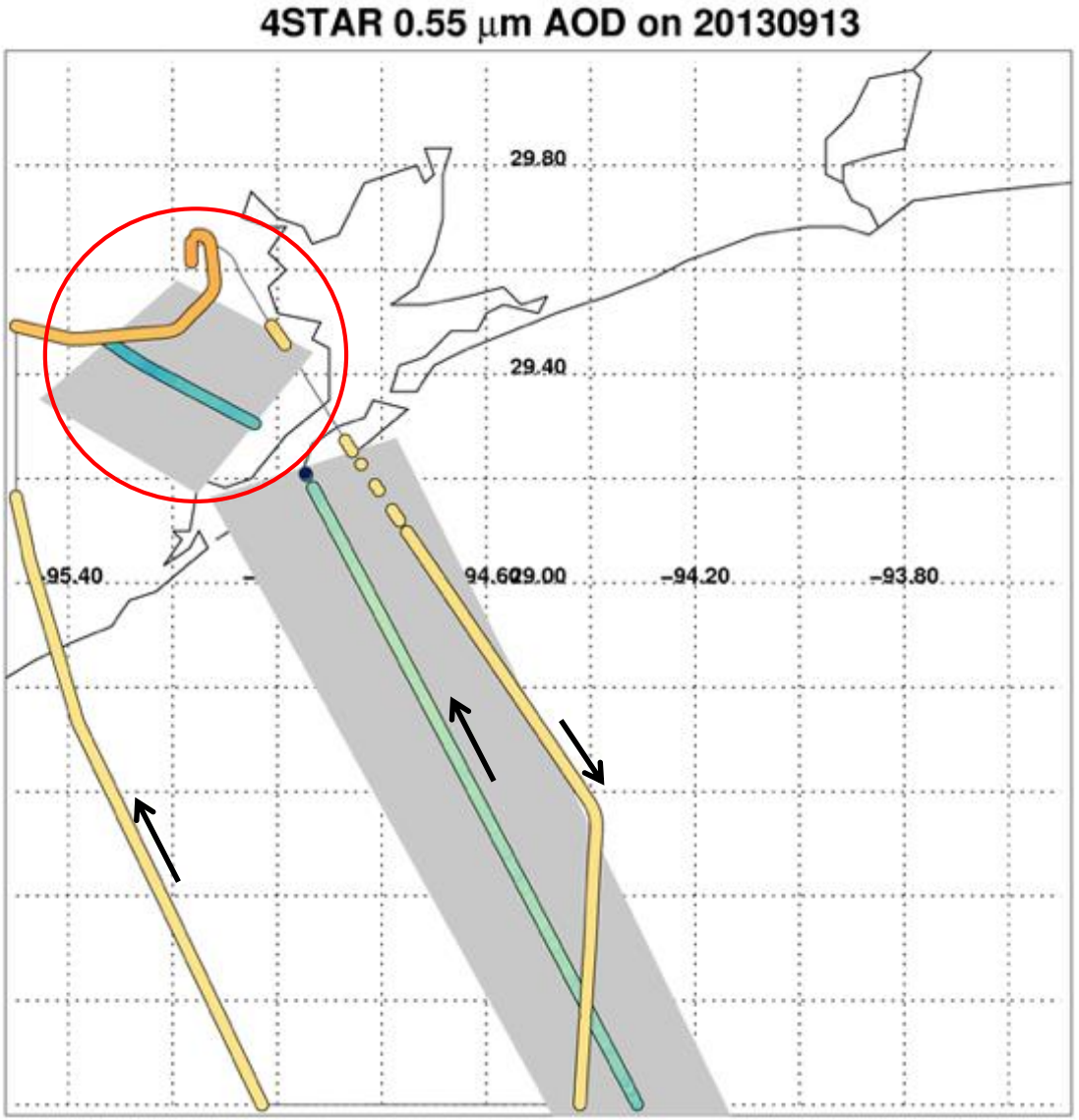
Wisc. Cloud Mask over RGB


MOD35–like Cloud Mask

Conf. Cloud Prob. Cloud Prob. Clear

CPL identified cloud

# A “validation” of sorts

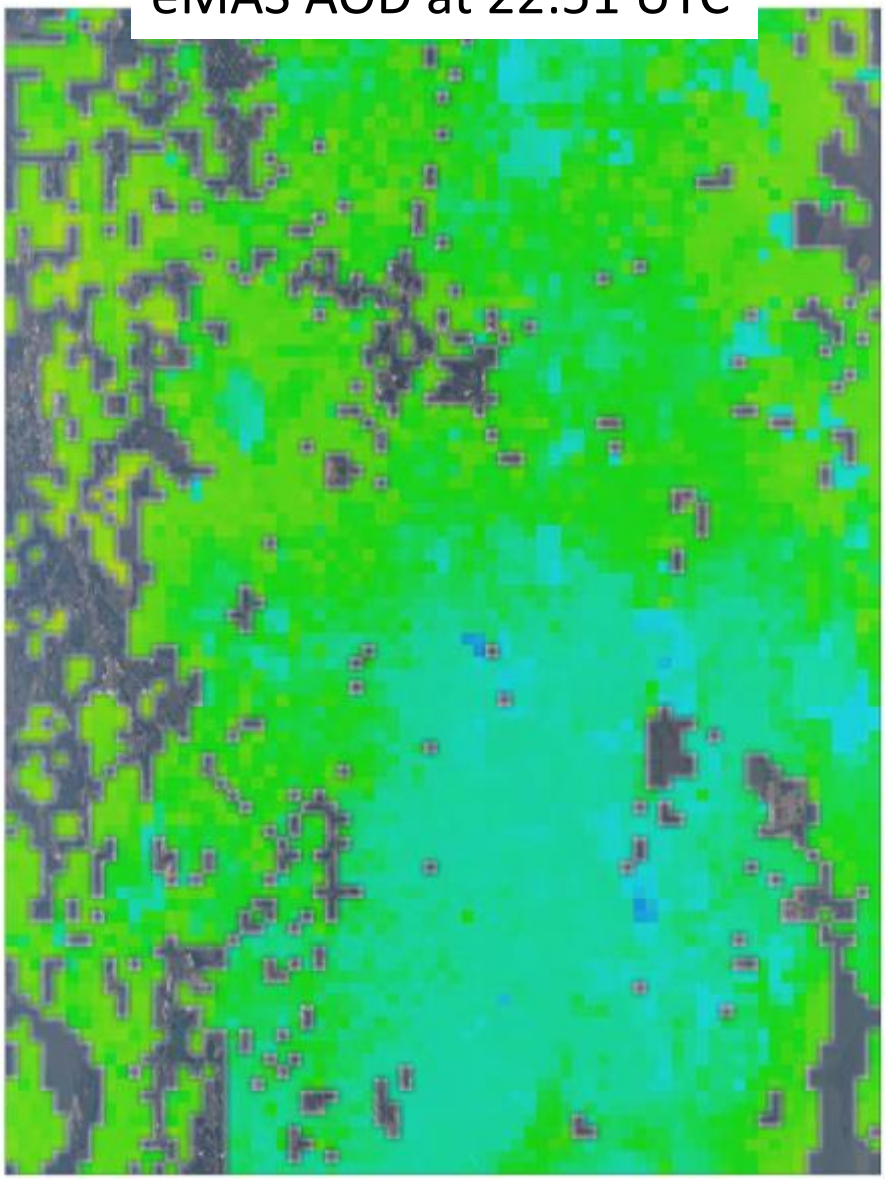


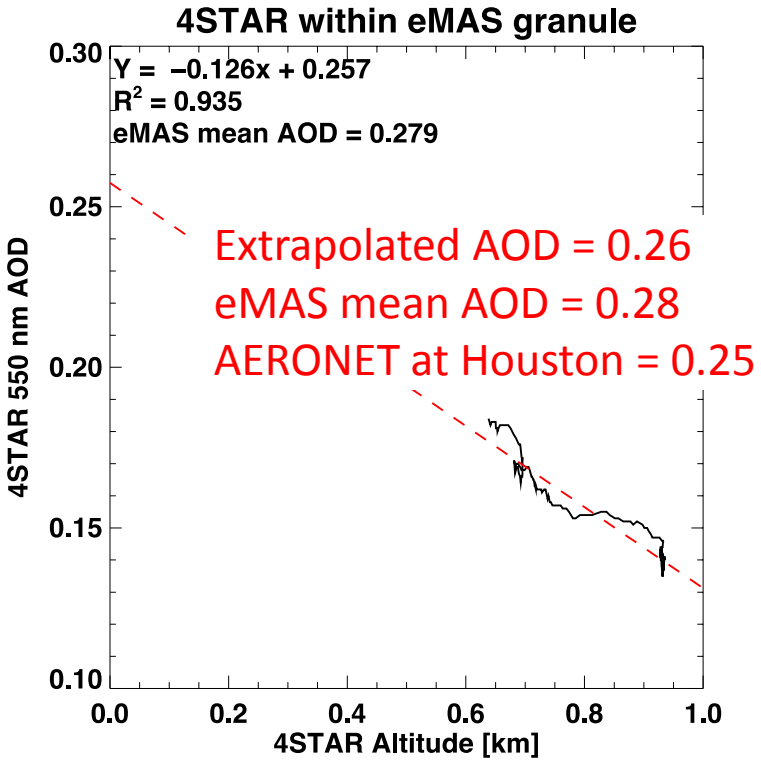

# Comparison with 4-STAR and AERONET: Sept 13

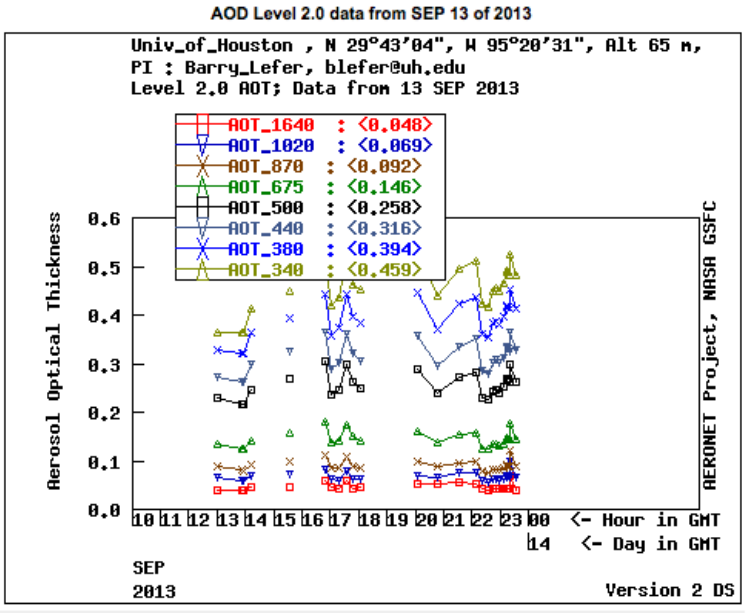
4-STAR

eMAS at Nadir

# eMAS AOD at 22:51 UTC



# Summary/So far

- MODIS/VIIRS satellite data are limited in quantifying aerosols close to clouds due to ~1km spatial resolution.
- After more than a decade of dormancy, the MODIS Dark-target algorithm has been ported to process MAS at ~50 m resolution.
- We applied to well-calibrated eMAS data during SEAC$^4$RS, and have derived AOD
- We see large AOD enhancements close to clouds (<5 km, and especially <2 km).
- Although we still have issues in relating to cirrus cloud and surface masking, these AOD enhancements are consistent with expectation
- Comparison with AERONET/4-STAR, far from clouds, suggests that eMAS AODs are “in the ball park”

# Summary/Next steps (1)

- Develop quick-looks and data that will be added to eMAS and SEAC4RS archives (including co-location, state boundary, etc)
- Collocate with AERONET and other sunphotometer data. Also with Terra/Aqua/VIIRS data – and attempt to "validate" within expected error envelopes.
- Evaluate other DT-derived aerosol properties (e.g. Angstrom, size, quality assurance)

# Summary/Next steps (2)

- Marshak/Varnai/Wen team will do magic as related to 3D corrections, especially in cumulus fields.
- Wilcox/Lao team will do magic in regards to modeling and analyzing the aerosol-cloud interactions for specific cases
- Participate/collaborate with other SEAC4RS teams, such as Aug 19 or Aug 30 case studies.
- Apply the algorithm to previous campaigns (CLAMS, TC4), as well as to future campaigns.